§73. Hydrogen Flux Measurements with Permeation Probes in Spherical Tokamak QUEST

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Hydrogen isotopes retention in the Plasma Face Materials (PFMs) of fusion devices is one of the critical issues for realization of fusion reactor and still remains an open issue. In order to control the neutral pressure and thereby the plasma density, the wall behavior should be well understood. Thus, it is important to know the flux distribution of all particles, ions, hydrogen atoms and molecules, coming to the plasma facing components (PFCs). A good solution for this problem could be permeation probes (PP), in which permeation of hydrogen through a thin membrane is measured. In the present work $Pd_{60}Cu_{40}$ (weight%) membrane was selected as membrane material [1].

Experiments are performed in the spherical tokamak QUEST [2] with the major and minor radii of 0.68 and 0.4 m, respectively. Schematic view of the tokamak cross-section is shown in Fig. 1. Working gas is hydrogen, supplied from a nozzle on the central stack (CS). Plasma is produced by electron cyclotron resonance (ECR) waves alone. Annular slab plasma is used in this study, indicated in Fig. 1. In the 'side' wall, a reciprocating permeation probe PP8 is installed, whose radial position can be changed in the range of ~1.0 - 1.4 m. Another four fixed PP positions are also shown in Fig. 1.

Cylindrical heater inside the membrane cylinder is used to keep the membrane temperature at the given temperature (300 ^{o}C) by the feedback loop (see Fig. 2). A stainless steel mesh supports the 20 μm thick membrane to prevent mechanical damage from the pressure differences. The detection area, A_{pp8}, of an uncovered PP8 (Fig. 2b) is ~7.5 x 10^{-3} m^2.

In order to calculate the incident hydrogen flux, Γ_{inc}, coming to a PP, diffusion problem is solved, as follows [3]:

$$\Gamma_{inc} = k_u c^2(0,t) - D[\partial c(x,t)/\partial x]_{x=0} \quad (1)$$

$$0 = k_d c^2(L,t) - D[\partial c(x,t)/\partial x]_{x=L} \quad (2)$$

$$\Gamma_p = k_d c^2(L,t), \quad (3)$$

where k_u, k_d are recombination coefficients on the upstream and downstream surfaces of the membrane, respectively. D and c are diffusion coefficient and hydrogen concentration in the bulk. x = 0 corresponds to the upstream membrane surface, and x = L to the downstream, with L being membrane thickness. t represents time. Parameters D, k_u, k_d and the permeated hydrogen flux in PP, Γ_p, are unknown. Discharges with constant parameters, where Γ_{inc} is constant, are used to find k_u and k_d. For D, a value from literature [4] is used, D = (2.9 ± 0.2) x 10^{-9} m^2 s^{-1}. Varying k_u, k_d and incident flux amplitude k_s ($\Gamma_{inc} = k_s\Gamma_{guess}$, where Γ_{guess} is assumed waveform of the incident flux, normalized to unity) are scanned and the best fit values are determined by minimizing $\chi^2 = (\Gamma_{exp} - \Gamma_{calc})^2/\Gamma_{exp}^2$, where Γ_{exp} is experimentally measured Γ_p, and Γ_{calc} is permeation flux, calculated with chosen parameters. As pointed out in ref.5), however, a different diffusion model should be used when the probe is contaminated due to deposition of impurity.

For each point of the experimental signal Γ_{exp} ($t = t_i$), Γ_{calc} ($t = t_i$) is calculated, and χ^2 ($t = t_i$) is minimized by varying k_s. This procedure allows a reconstruction of the amplitude and waveform of the Γ_{inc}. An example of such calculations is shown in Fig. 3. A peak in the Γ_{inc} (Fig. 3a) at the beginning of the discharge is usually due to plasma ignition. In this particular discharge after ~250 s Γ_{inc} rose due to an increase in plasma density, and this behaviour is successfully reproduced by the fitting procedure (Fig. 3b) [1].

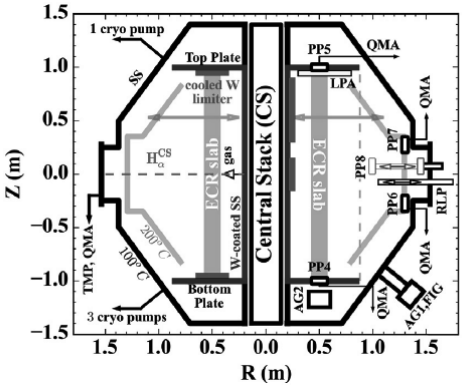

Fig. 1. Cross section of QUEST tokamaks. Permeation probes (PP4,5,6,7), movable PP8 – rectangles, are shown.

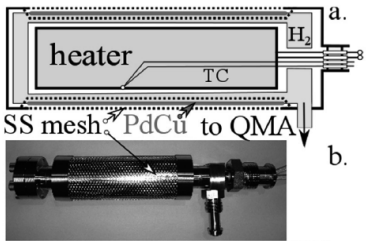

Fig. 2. (a) Schematic view of the PP cross-section: PdCu membrane. (b) Photo of a probe without protection cover.

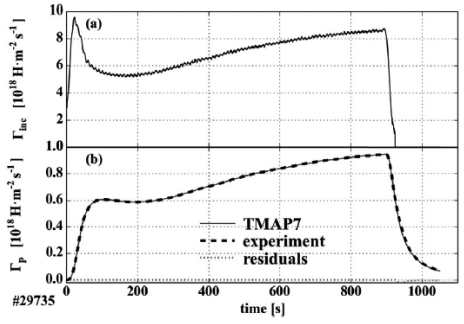

Fig. 3. (a) Γ_{inc} calculation result. (b) Γ_p, experiment (dashed line), calculated (solid line) and residuals (broken line).

1) Kuzmin A. et al., Vacuum, in press.
2) Hanada, K. et al., Plasma Sci. Technol. **13** (2011) 307.
3) Takagi, I., J. Nucl. Sci. Technol. **29** (1992) 947.
4) Piper, J., J. Appl. Phys. **37** (1966) 715.
5) Hanada, K. et al., J. Nucl. Mater. **463** (2015) 1084.